# High Efficiency Miniature Piezo Motors

**SB992-0037 Contract #DAAH01-00-C-R039**

## DARPA Smart Structures Technology Interchange Meeting

**Baltimore, MD**
**27 June 2000**

**Presented by:**

**Eric H. Anderson**

**CSA Engineering Inc.**

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# Objectives and Scope

- Piezoelectric motors present an alternative to electromagnetic motors
- Goal is piezoelectric rotary motor that replaces friction interface with genuine mechanical interface
  - Reduced wear and increased reliability
  - Greater output and holding torque
- One objective is to maximize overall efficiency of electromechanical device
  - Integrated electromechanical design
  - Resonant pulsed electronic drive
- Concept being developed exploits suspended whirling stator driven at frequencies up to and including suspension resonant frequency
- Prototype testing with 20 mm diameter device

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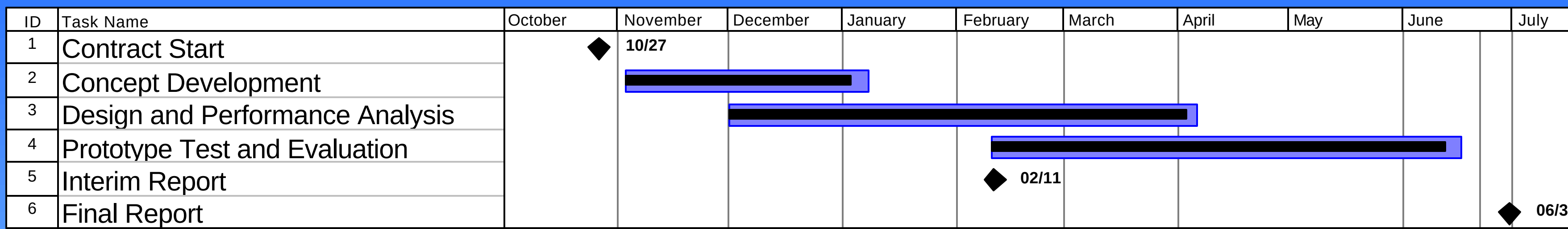
# Program Schedule and Milestones




- **Eight-month Phase 1 feasibility study is wrapping up**
- **Present effort**
  - **Final tests using prototype motor**
  - **New concepts based on lessons learned**

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# Team Member Responsibilities and Status

- **CSA Engineering, Inc.**
  - Project lead, electromechanical design, microcontroller, power delivery, test and evaluation
  - Status: finishing up testing and documentation
- **Warner Precision Engineering**
  - Electrical design and power delivery
  - Status: several designs considered, prototype drive delivered
- **Rhombus Consultants Group**
  - Conceptual design, analysis, test and evaluation
  - Status: conceptual design complete, analysis methodology developed and documented, simulation software written, supported test & evaluation efforts
- **Overall current work on drive optimization for performance and incorporation of lessons learned into future prototype concepts**

# Accomplishments

- **Gear-driven piezoelectric motor concept derived**
  - Design parameters optimized for low loss operation
- **Prototype motor developed**
  - Laser machining process developed for 34-tooth, 25 mm outer diameter rotor
    - » Polycarbonate material
    - » Gear feature size O(0.1–0.5 mm)
  - Piezoelectric multilayer bimorph drivers
  - Programmable waveform PWM drive electronics
- **Motor concept validated**
  - Bi-directional operation achieved up to stator resonance

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# What Has Been Gained / Learned

- **Lessons Learned**
  - **The Concept Works!**
    - » **Bi-directional motion at top speed achieved**
  - **Motor operation is highly sensitive to alignment and positioning tolerances**
    - » **Artifact of relatively low actuator displacement**
  - **Output torque is reduced by tolerance buildup**
  - **Non-sinusoidal drive waveform required for best torque output**
    - » **Drive waveform optimization will drive next-generation electronics design for overall efficiency**
    - » **Charge pulse drives appear very promising**
  - **Programmable, generic drive electronics have proven highly valuable for prototype development**
- **Continuation of research will increase speed and torque, with extension to smaller sizes**

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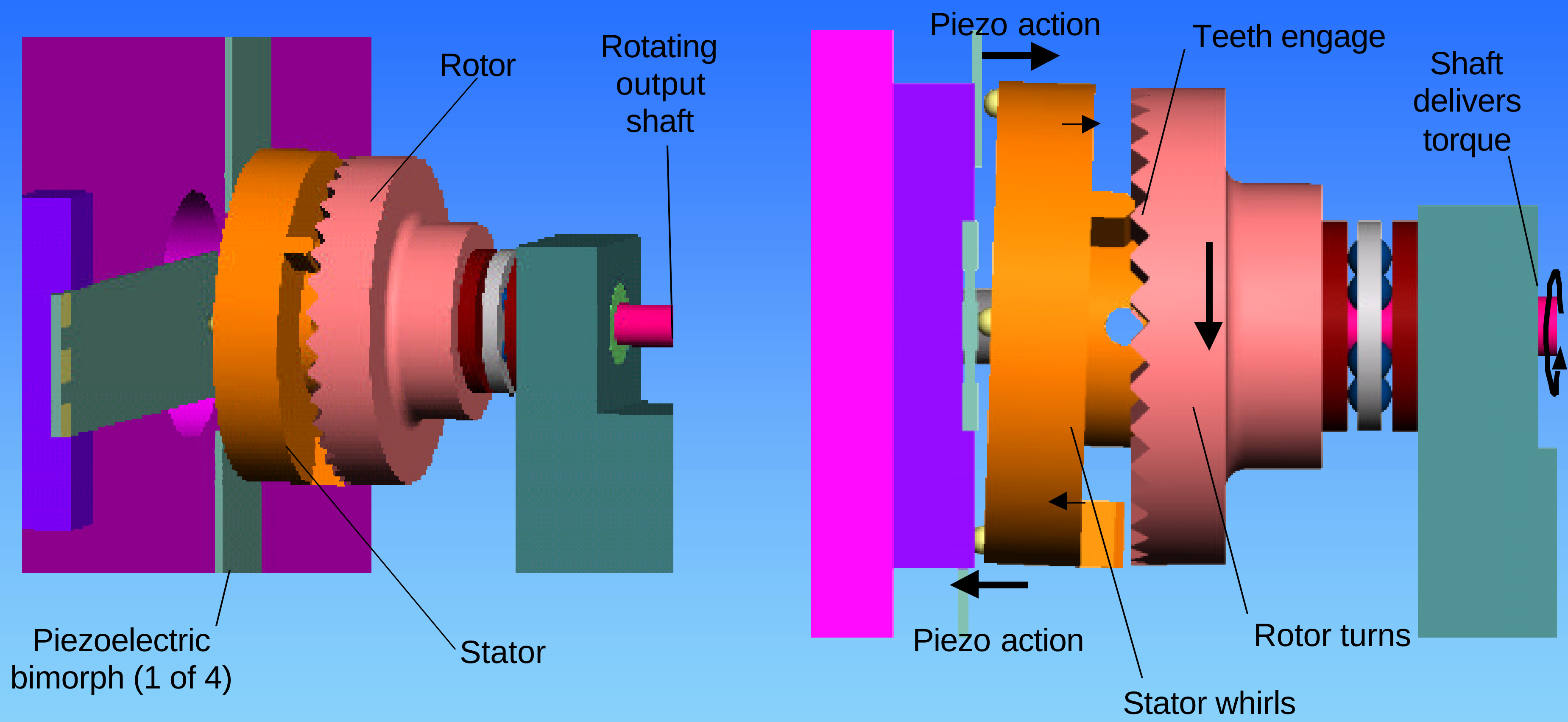
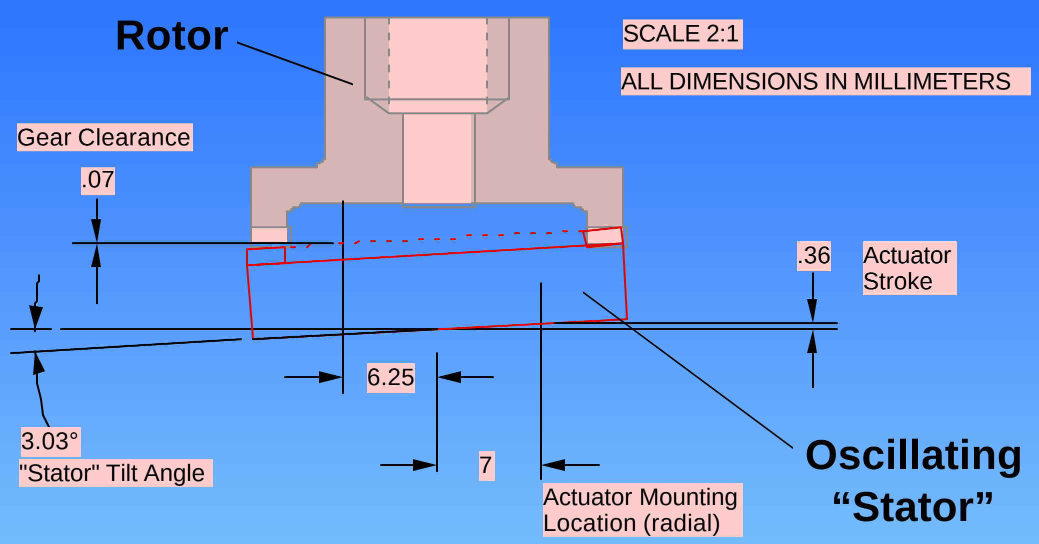
# Piezoelectric Motor Operating Principle




- **Principle: whirling stator directly drives rotor**
- **Current concept uses piezoelectric bimorphs; future design will employ compact optimized piezo geometry**

# Motor Design




- **Rotor**
  - **34 teeth on 20 mm diameter, 90° cut**
  - **Laser machined with 5 mm wide teeth**
- **Stator**
  - **3 teeth on 20 mm diameter**
  - **0.4 mm actuator stroke required (nominal)**
  - **Pivot center fixed by ball joint and torque link**

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# Piezomotor Gears

rotor tooth

**Laser machining for ~1 mm feature sizes**

**Process scales well to objects one-tenth size**

**Several parts with different angles fabricated**


Close-up of stator gear


Close-up of 34-tooth rotor

Gear alignment

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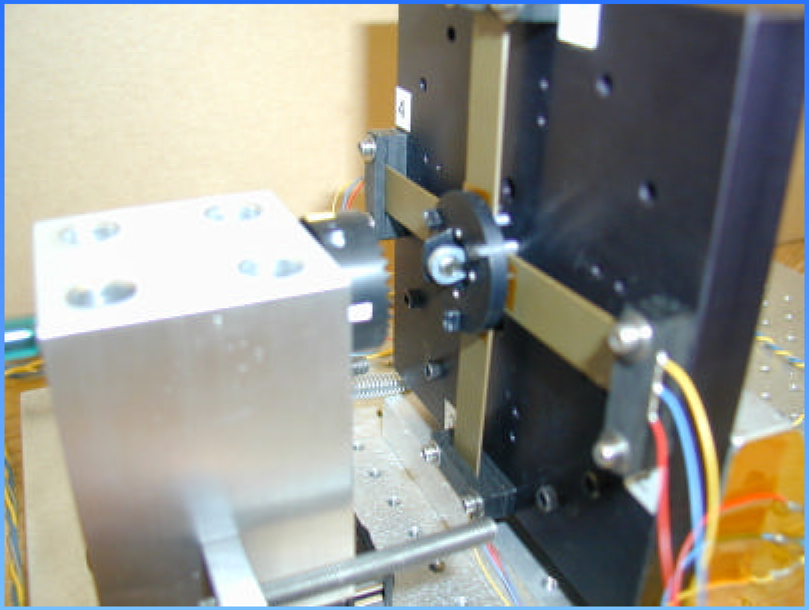
# Laboratory Demonstration Hardware



Rotor (left) shown retracted from stator

- **Testbed allows investigation of mechanical and electrical components**
- **One-axis precision linear stage used to position rotor**

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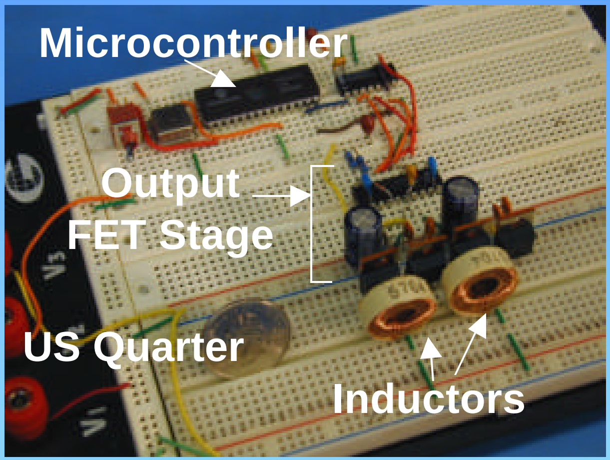
# Prototype Piezomotor Drivers

- **First generation driver**
  - Quick and simple laboratory prototype
  - Labview app. interfaces with microcontroller, sets direction and rate
  - On/Off piezo control - binary state output lacks waveform control
  - Inefficient - lacks mechanism for energy “recovery”
- **Second generation driver**
  - Pulse width modulation (PWM) output
  - More efficient energy delivery - energy recovery through inductive filter
  - Improved waveform flexibility - 8 bit, 128 pt. software programmable lookup tables
  - Actuation symmetry exploited for reduced electrical overhead
  - Typical power draw: 0.9 to 1.3 Watts (total, 5 V and 60 V inputs)




Drive freq → Micro-controller → PWM → Push-pull FET stage (2 ch.) → Inductors → Filtered signals → Electromechanical hardware

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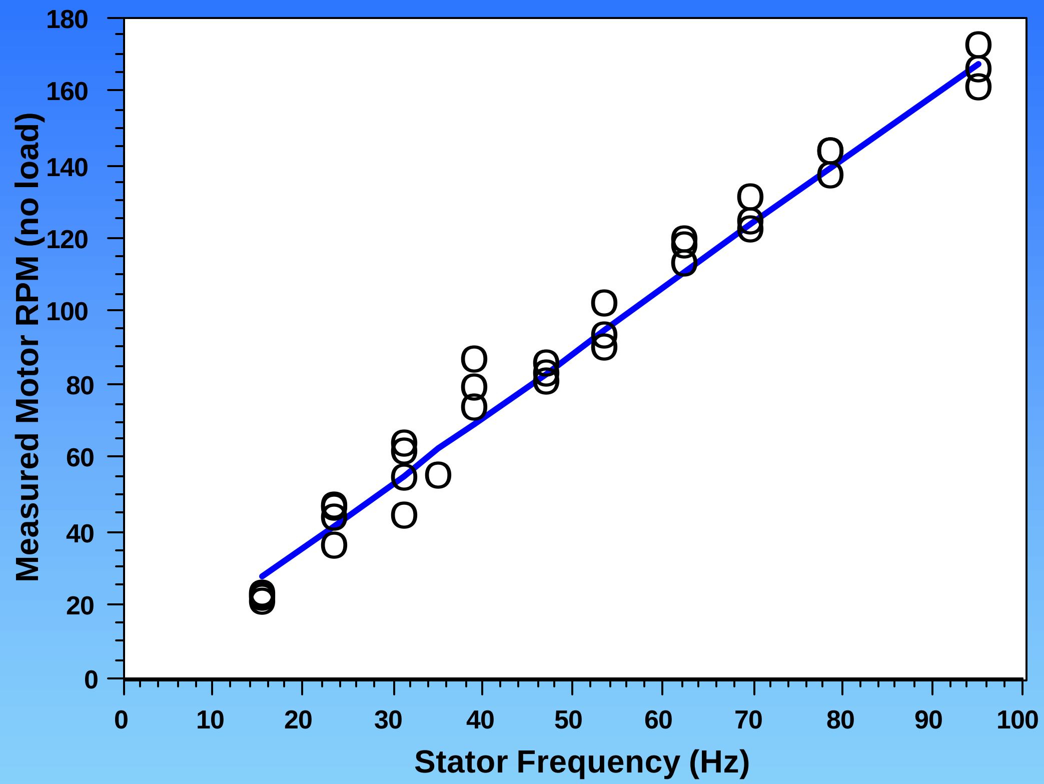
# Motor Performance




- **Motor speeds measured up to stator resonance**
- **Bi-directional operation demonstrated**
  - **Speeds vary with direction due to alignment differences**

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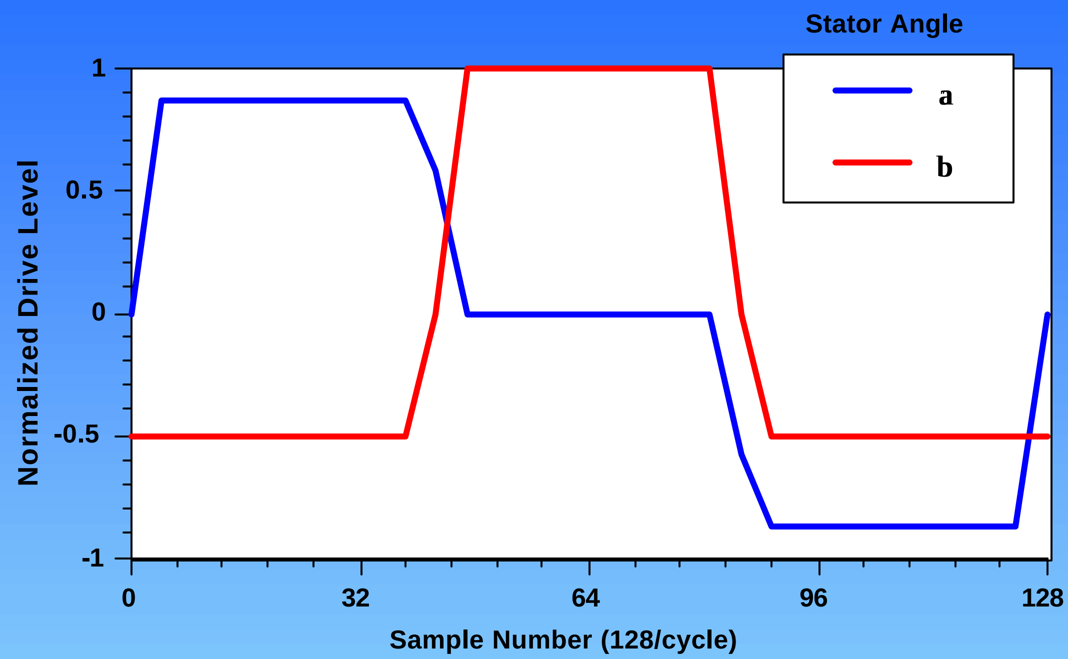
# Drive Signal Optimization




- **Torque Optimization**
  - Maintain rotor-stator contact through 80% of stator cycle
  - Maximum speed is reduced ~20%
  - Allows drive electronics optimization (e.g. charge pulse)
  - Currently in testing

# Electrical Optimization

- An simple next step - printed circuit board driver but with retained flexibility with flash EEPROM microcontroller (approximate 1.5 in$^2$)
- Develop one-chip custom electronic assembly
- Concepts for optimization based on symmetry and well defined operating region
  - Eliminate microcontroller - generate fixed waveform with discrete electronic hardware
  - Explore complementary reactive coupling to shuttle electric energy to opposing elements
- Pulsed resonance configuration
  - Lightly damped electrical resonance is excited at natural frequency - minimal energy input
  - Low overhead, fixed frequency operation
  - Recently demonstrated on similar piezo system

# Piezomotor During Operation